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POST-DISCRIMINATION GRADIENTS AROUND STIMULI WITH DIFFERENTIAL RATES OF OCCURRENCE IN A DISCRETE RESPONSE TASK

Donald B. Cameron

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-62-352

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Operational Applications Laboratory
Deputy for Technology
Electronic Systems Division
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L. G. Hanscom Field, Bedford, Mass.

Project 9674, Task 967406

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ABSTRACT

Generalization gradients in an identification-type task reflect the willingness to apply identifying labels to stimuli which deviate from what might be called the "ideal standard" of a class. After training subjects to discriminate between pairs of ideal standards varied in both discriminability and frequency of occurrence it is shown that post-discrimination generalization gradients are characterized by a redistribution of identifying responses around the more frequent standard as a function of discriminability.

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INTRODUCTION

Inherent in an overview of man-machine interfaces and machine to man data transduction are the essential criteria of extending and, where possible, enhancing man's natural sensors to provide the necessary and sufficient information upon which the perceptual behavior of recognition and identification of an ongoing event can be performed prior to the dependent behaviors of decision and action selection. The desirable level of perfect or near perfect perceptual accuracy in recognition and identification is frequently prohibited by conditions associated with the external system environment.

The primary characteristics of the external environment which prohibit identification with certainty lie in the nature of the external event itself. Such events, for the more complex systems and indeed in many simple everyday situations, are characterized as being non-repetitive in the sense that each successive occurrence contains some degree of variation from what might be called an "ideal standard". Identification of these varied events is therefore done in terms of specifying the standard which generated the event rather than in determining whether or not each specific event has occurred before. The degree of willingness to apply the label associated with the ideal standard to event variations forms a stimulus discrimination or stimulus generalization gradient which is characterized by a decreased willingness to apply the label as the difference between the ideal standard and ongoing event increases. The post-discrimination gradient reflects this degree of willingness to apply an identifying label after the operator has been trained to discriminate between two or more ideal standards.

Recent studies in the area of stimulus generalization following such discrimination training procedures have shown predictable shifts in gradient peaks and response rates to differentially reinforced training stimuli. After training on two stimuli along a light wave length continuum Hanson (7, 8) has shown that gradients of operant response rate measured during extinction undergo orderly changes as the training stimuli become more difficult to discriminate from each other. Subjects were trained to respond in the presence of one light wave length value and not to respond in the presence of a second value. As the two wave lengths were moved closer for separate groups, post-discrimination gradients indicating the ability of additional wave length values to elicit the trained response showed that a maximum number of conditioned operant responses were elicited by stimuli not included in the training series. As the two training stimuli were made more difficult to discriminate, the wave length value eliciting the maximum number of responses in the post-discrimination test moved further away from both training stimuli.

A second study, by Guttman (4), used the same values of light wave length as training stimuli but trained the operant response to occur in the presence of both stimuli rather than one. Responding in the presence of the wave lengths was differentially reinforced, on the average of once per minute for one wave length and once per 5 minutes for the second wave length. Results were almost identical with those of Hanson; the maximum number of operant responses in the post-discrimination test session was elicited by a value of wave length not presented in the training sessions. Low rates of reinforcement were concluded to be as inhibitory as no reinforcement when the low rate is combined, in a discrimination task, with a high rate of reinforcement in the presence of the alternative stimulus.

Equal rates of reinforcement for responding in the presence of discriminated stimuli yield post-discrimination shifts in the stimulus values eliciting the maximum number of operant responses which differ from those resulting from differential reinforcement. Studies by Guttman and Kalish (5, 6) and also Kalish and Guttman (9) used two and three values of light wave length as training stimuli. Operant responding in the presence of these stimuli was equally reinforced. A generalization test session, under extinction conditions, indicated that the intermediate stimuli between the training stimuli, rather than the extreme stimuli as in the differential reinforcement condition, elicited more operant responses than could be predicted from interacting single stimulus generalization gradients. In addition, as the training stimuli were made more difficult to discriminate, the maximum number of responses was elicited by a wave length value halfway between the two training values of wave length.

Carterette (1) adapted the general paradigm of discrimination training followed by generalization testing to a discrete response task with human subjects. Using apparatus which enabled presentation of a square of light at different positions along a horizontal line, subjects were trained to discriminate between two specific positions as standards A and B. Three levels of separation of standards were used with an equal number of presentations occurring in each of the standard positions. Response behavior required the subject to identify test stimuli located at other positions along the continuum as being either one of the two standards or different than the standards. Although done within the context of a mathematical model derived from the Estes-Burke (2, 3) probabilistic theory of behavior, the results substantiate the findings of the Guttman and Kalish studies under equal reinforcement conditions for operant behavior. Gradients varied from definite bimodality for maximum separation of standards to unimodal curves with peaks midway between standards for the minimum separation level.

This study applies the methodological procedures of discrimination training followed by generalization testing to discrete identification responses by human subjects under conditions of differential reinforcement. Its purpose is to test the applicability of Guttman's (4) conclusion, derived from operant behavior, that low rates of reinforcement are as inhibitory as no reinforcement when the low rate is combined in a discrimination task with a high rate for the alternative stimulus. If applicable, it must be predicted that the maximum number of positive identifications represented by a post-discrimination gradient would center about the more frequently reinforced response. In addition, as discriminability between standards is decreased a peak shift would occur which would place the maximum number of responses to the extreme side of the more reinforced standard rather than to the side between standards. To test these admittedly rather general predictions and more importantly to determine the effect of varied frequency of reinforcement on the discrete identification of standard stimuli by human subjects the following conditions were established:

1. Four sets of two accute angles each were varied in discriminability as a function of differences in angular rotation between the two angles of each set.

2. The two angles of each set were then used as discriminated events in a training series which required subjects to predict which of the

the two angles, called standards A and B, would be the next to occur. Actual frequency of occurrence was varied through separate conditions.

3. The training series was followed by a generalization test which required subjects to indicate whether a series of test angles were the same as standards A or B or different.

4. The results of this test were then compared with single, non-discriminated standard stimuli of the same size.

5. Response measures were analyzed for differences in the number of "same as A" and "same as B" identifications as a function of both levels of discriminability and frequency of the standards during the training series.

SUBJECTS

Two groups of college girls were used as subjects. Group I, consisting of 50 subjects was used as a control group from which single stimulus generalization gradients were determined, Group II, consisting of 40 subjects, was used as the experimental group in the main body of the study.

APPARATUS

All even numbered angles between 8 and 88 degrees (8, 10, 12,..... 84, 86, 88) were photographed on high resolution and maximum contrast 35mm M402 Kodak Micro-File. Films were cut and mounted for slide presentation. Presentation equipment consisted of a Bell & Howell 750 Robomatic slide projector and a rear projection screen. The screen consisted of a wood frame holding a sheet of white drafting paper. The paper was masked with an opaque black sheet of cardboard from the center of which a 12 diameter circle had been cut. The angles were projected on the exposed circular area of the screen and were seen as white figures on a uniform black background. The sides of a projected angle were 6" long and 1/2" wide. The base of all angles appeared in the same position on each exposure. Viewing distance was maintained at three feet.

PROCEDURE

I. Single Stimulus Generalization Gradients (Control Group)

The angles 20^o, 36^o, 40^o, 50^o, 60^o, 76^o, were selected as standards. Each standard was compared with itself and with the six even numbered angles above and below it. The standard appeared for one second followed by a three second pause, and then the comparison angle appeared for one second. Each subject was required to indicate whether the comparison angle was smaller, the same as, or larger than the standard angle. This was continued until each subject had judged each angle four times, a total of 200 judgments for each standard and comparison angle. Order of presentation of the standard versus comparison sets was randomized.

II. Discrimination Training (Experimental Group)

Four sets of two angles each were selected as standards in the training series. These sets were selected to vary difficulty of discriminability between the standards. Levels of difficulty were selected from standard psychophysical studies using various size standards in j. n. d. determinations. The most difficult to discriminate set was (40^o vs. 50^o) the easiest being (36^o vs. 60^o). Intermediate in discriminability were (60^o vs. 76^o) and (20^o vs. 36^o).

Four sets of random distributions of the occurrence of two events were made so that each set had a specific restriction with respect to the frequency of occurrence of the first angle, called angle A, of each set. These restrictions were: for set No. 1- angle A must occur on 80% of all training trials; for set No. 2- angle A must occur on 70% of all training trials; for set No. 3- 60% and for set No. 4- 50% of all training trials must be a presentation of angle A. Table I, shows the actual frequencies of exposures of the standard angles.

Each set of occurrences was then combined with each set of standard angles, a total of 16 combinations. The 40 subjects of Group II were randomly divided into four equal subgroups. Each subgroup was assigned 4 of the 16 combinations of occurrence and discriminability sets in such a way that each occurrence set and each discriminability set occurred only once for each group. This program is summarized in Table II.

Each training session consisted of a sequence of presentations of either one of the angles in the standard set. Each presentation was a one second exposure of the angle preceded by a red warning light of three seconds duration. Subjects were instructed to predict which of the two angles would be shown following the warning light. Predictions were made while the warning light was on[1]. Emphasis was given to achieving the highest number of correct predictions. This form of training was designed to establish differential expectancies and provide a post session check on the subjects' ability to discriminate between the two standard angles of each set. In addition, it provided the subject with immediate knowledge of the correctness of her prediction.

III. Generalization Test (Experimental Group)

Testing immediately followed the training series. Subjects were

TABLE I

Frequency of Exposure of Standards During Training

Set Number	Standard Angles	Exposures of Angle A	Exposures of Angle B
1	40° vs. 50°	160	40
2	60° vs. 76°	140	60
3	20° vs. 36°	120	80
4	36° vs. 60°	100	100

TABLE II

Experimental Design for Discrimination Training

Per Cent of Occurrence	Angles 40° vs. 50°	Angles 60° vs. 76°	Angles 20° vs. 36°	Angles 36° vs. 60°
80% A-20% B	S-I, 1*	S-III, 4	S-II, 4	S-IV, 2
70% A-30% B	S-II, 2	S-I, 2	S-IV, 1	S-III, 1
60% A-40% B	S-III, 3	S-IV, 3	S-I, 3	S-II, 3
50% A-50% B	S-IV, 4	S-II, 1	S-III, 2	S-I, 4

*Indicates that subgroup I received 40° vs. 50° as standards in the first experimental session. Within that session angle A, (40°) appeared on 80% of all training trials.

shown a series of angles which included the two training angles, all even intermediate angles, 4 even numbered angles larger than angle B, and 4 even numbered angles smaller than angle A. For example, the 40° vs. 50° set consisted of all even angles between and including 32° to 58°. This series of test angles was arranged in random order and presented twice, once forward and once backward. The sequence consisted of a one second exposure of the angle followed by a three second interval during which the subjects were required to indicate whether the angle was the same or different than either one of the training series angles. If the judgment was that an angle was different, a second judgment was required as to which of the training angles the new angle was most like.

Each subgroup had four of the training-testing sessions with each session separated by at least 24 hours.

RESULTS

I. The Single Stimulus Control Gradients

Gradients of "same" responses for single stimuli are plotted in Figure 1 as a percentage of the total number of responses for each stimulus value of the continuum around each single standard. "Same" responses in the single stimulus task are equated with "same" judgments in the paired set testing task and are therefore used as a basis for analyzing the effect of differences in frequency of occurrence and pair discriminability in the paired set task.

Figure 1 shows the gradient of "same" responses around each single standard stimulus. The gradient slopes are uniform with respect to left side to peak vs. right side to peak comparisons for each standard. Although not statistically significant, uniform differences are apparent in the number of "same" responses elicited when each standard is compared with itself. The number of "same" responses is inversly related to the distance in angular rotation between the standard angle and the arbitrary reference angles of 0° and 90°. As the size of the standard angle approaches 45° from either direction, the per cent of "same" responses given to standard vs. standard comparisons decreases. Table III shows that the 20° standard when compared with itself elicits 81% of the responses as "same". The values of standard vs. standard comparisons for the 36°, 40°, 50°, 60°, and 76° standards are 72%, 68%, 64%, 67% and 71% respectively.

Further, differences are noted in the per cent value of the number of "same" responses compared with the total number of responses. The general finding, with the exception of the continuum of test stimuli with

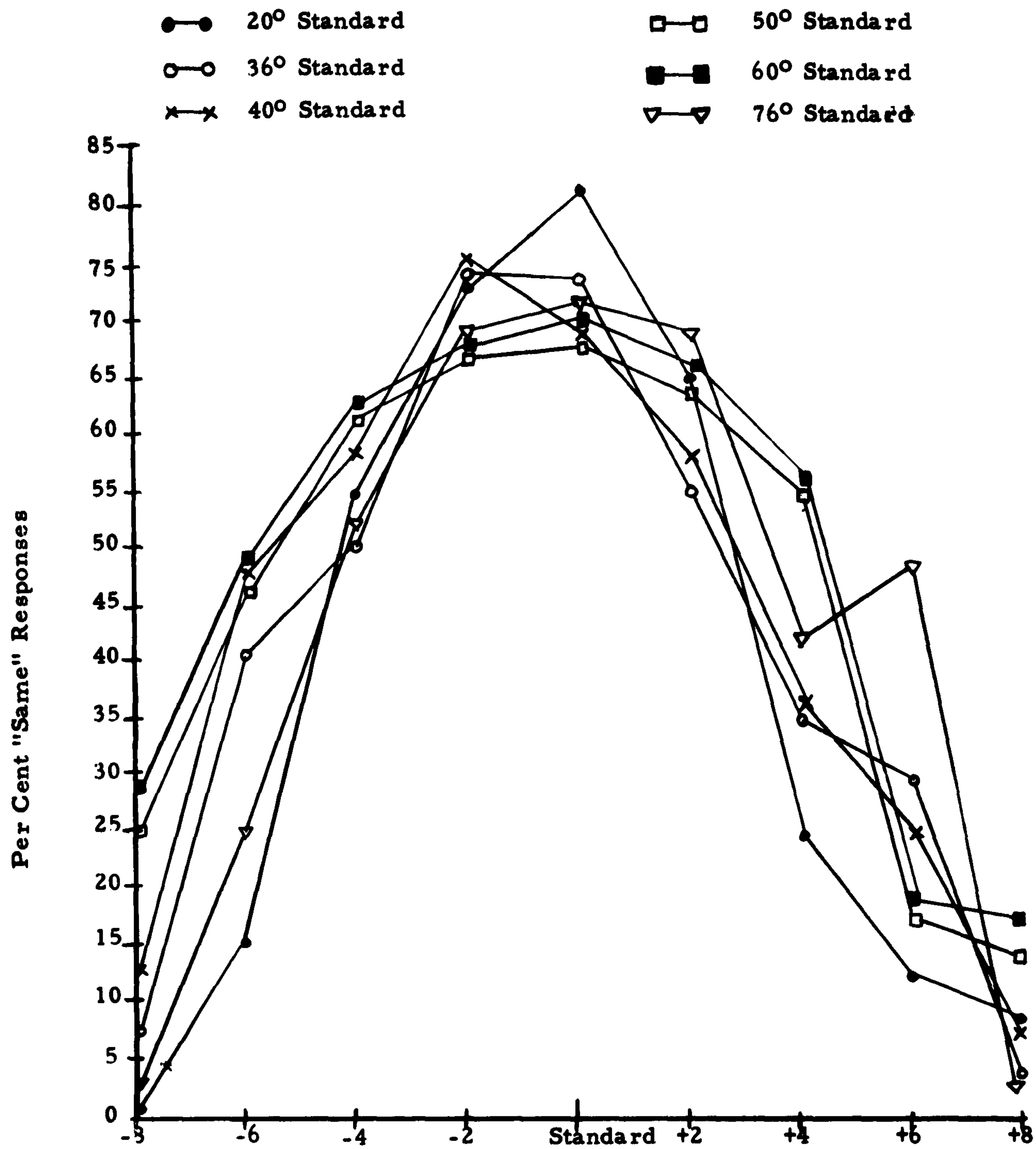

Figure 1. Gradients of "Same" Responses for each Standard Stimulus Value in the Single Stimulus Control Condition

the 76° standard as its center, is a percentage directly related to the size of the standard stimulus. As indicated in Table III, 26% of all responses given to the 20° continuum were called "same". Values for the 36°, 40°, 50°, 60° and 76° standard continua were 29%, 31%, 31%, 35% and 30% respectively.

TABLE III

Data Describing Distribution of "Same" Responses for each Single Stimulus Control Gradient

	Standard Stimuli for Each Control Gradient					
	20°	36°	40°	50°	60°	76°
Per Cent "Same" Responses for Standard vs. Standard Comparisons	81.2	72.6	68.6	65.5	66.5	71.6
Per Cent of Total responses which were called "Same"	26.9	29.5	31.1	31.1	35.5	30.3
Per Cent of "Same" Response to Left of the Standard	55.0	56.1	58.9	59.3	55.5	48.9

Significant differences are noted in the distribution of "same" responses around the standard stimulus of each single stimulus continuum. Again with the exception of the 76° series, a greater percentage of the total number of "same" responses is elicited by the smaller size test stimuli located to the left of the standard stimulus. As shown in Table III, the specific values increase as the size of the standard stimulus approaches 45° and then decreases as the size of the standard continues to increase.

II. Comparison of the Single Stimulus Control Gradients with Paired Set Gradients

A. Redistribution of "Same" responses as a function of frequency of occurrence of the standard stimulus in the training task.

Figure 2 shows the percentage of "same" responses for each of the test stimuli in the post-discrimination gradients around the standard stimuli used as A in the training series. The plotted gradients are the pooled data from the four percentages of occurrence (80%, 70%, 60%, 50%) of standard A in the training series and are compared with the single stimulus control gradients of the same size. As is apparent by inspection, the post-discrimination gradient around each standard has shifted toward the largest test angles in terms of both peak and per cent of "same" responses to the left of the standard. Differences in distribution of "same" responses between the control and post-discrimination gradients are significant beyond the .01 level.

Comparing the proportion of "same" responses which occur to the left side of the standard for the control gradients shows 55%, 56%, 59% & 55% for the 20^{o}, 36^{o}, 40^{o} and 60^{o} standards respectively. Similar Proportion for the post-discrimination gradients are 31%, 29%, 40% and 37% for the 20^{o}, 36^{o}, 40^{o}, and 60^{o} standards, a significant redistribution of "same" responses which is indicative of a shift of response frequency toward the larger angles in the test series.

A breakdown of the pooled post-discrimination gradients into a separate gradient for each level of occurrence of standard A in the training series reveals significant differences in the extent of the shift as a function of per cent of occurrence. Again using the response data of proportion of "same" responses elicited by the test stimuli to the left of the standard stimulus, Table IV shows that as the frequency of Standard A

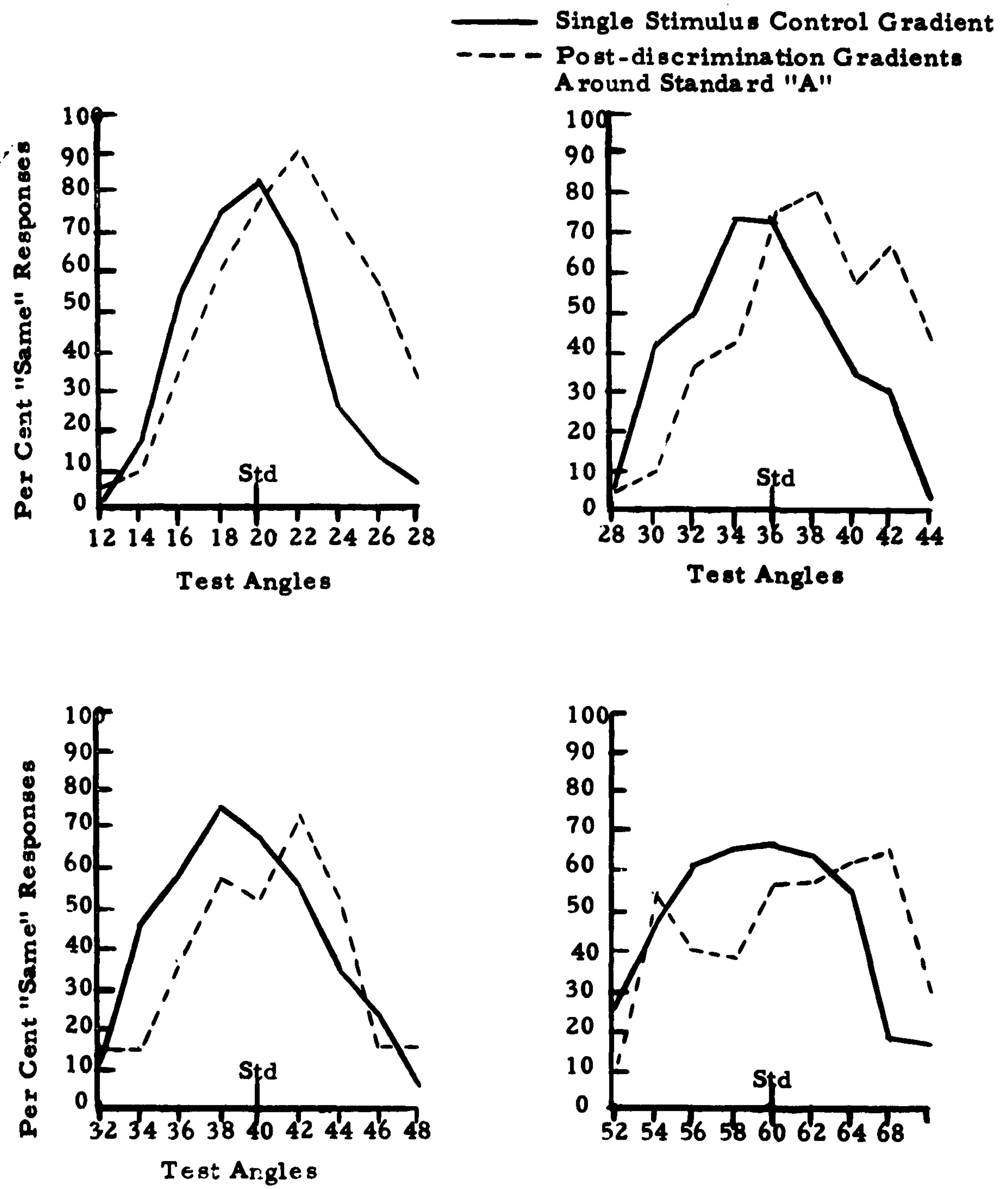

Figure 2. Comparison of Post-Discrimination Gradients Around More Frequent Standard Angles "A" with Single Stimulus Control Gradients

increases in the training series the subsequent proportion of "same" responses to the left of the standard in the post-discrimination gradient tends to decrease. The exception to this is the 40° standard which shows no regular or significant variation as a function of occurrence of the standard in the training series. Figure 3 graphs the extent of post-discrimination gradient shift as a function of frequency of occurrence of the standard angle A for the 20° standard only. It is apparent that all of the

TABLE IV

Per cent of "Same" Responses which occur to the Left Side of Standard Stimulus A for each Level of Occurrence as Compared with the same Data for the Single Stimulus Control Gradients

Std Angle A	Single Stimulus Control	Per cent of Occurrence of Standard A During Training Series 50%	60%	70%	80%
20°	55.00	42.15	32.35	27.56	23.30
36°	56.07	47.12	36.27	21.25	15.00
40°	58.96	28.33	47.29	31.48	54.63
60°	55.48	56.86	40.54	29.76	21.42
	$\overline{X}$	43.61	39.11	27.51	28.58

post-discrimination gradients for this standard have shifted to the right or larger test stimulus values with the greatest shift and highest peak values being associated with the gradient around standard A when this standard occurred on 80% of the trials in the training series. As the frequency of occurrence of standard A in the training series decreases the extent of the subsequent shift in the post-discrimination gradient decreases.

The dependency of extent of shift of the post-discrimination gradient

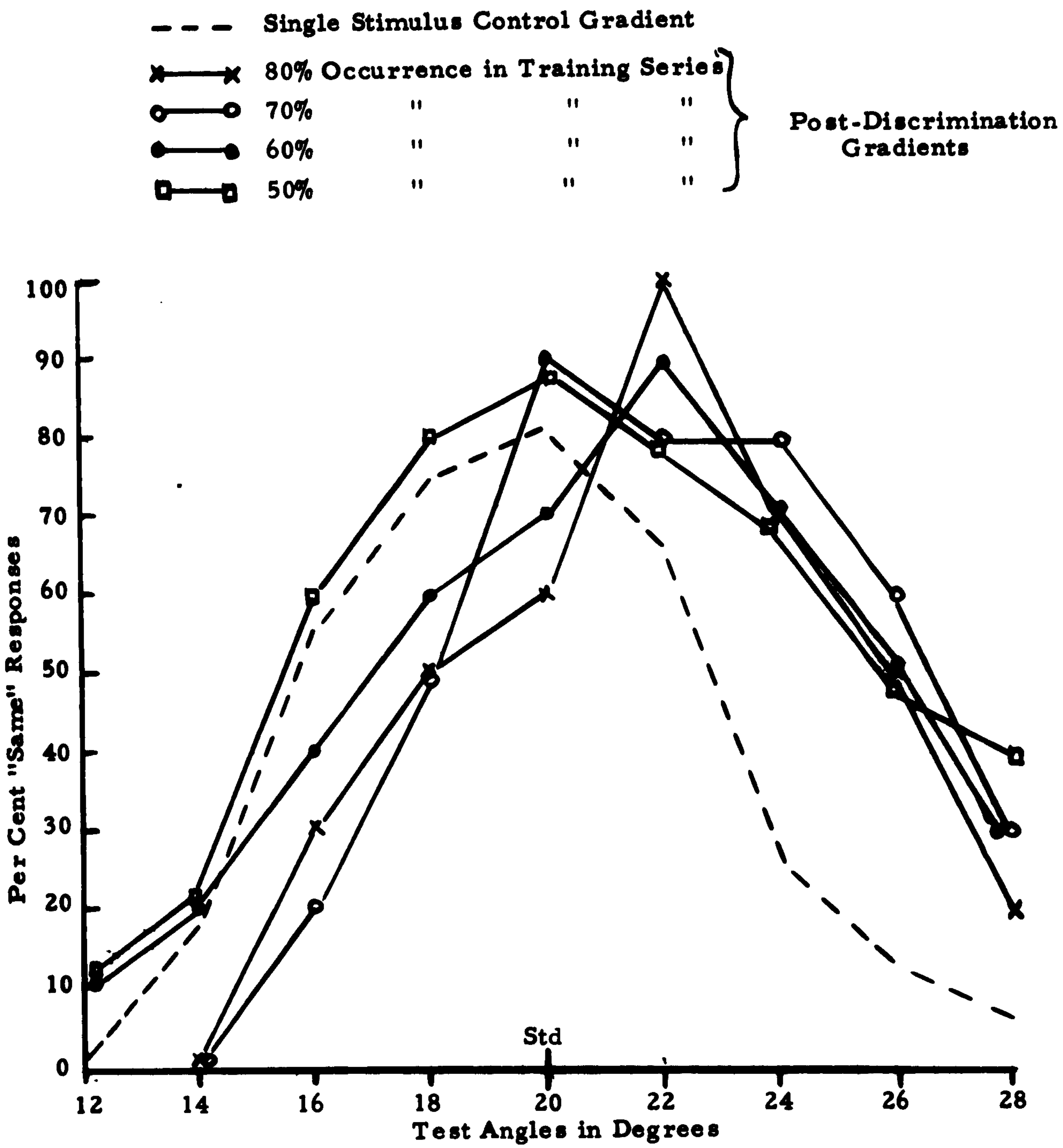

Figure 3. Redistribution of Shift of "Same" Responses in the Post-Discrimination Gradient around the 20° Standard as a Function of Per Cent of Standard "A" Occurrence in the Training Series.

on the antecedent frequency of occurrence of the standard during the training series is not observable for those standards used as B with occurrences of 50%, 40%, 30% and 20% of the training trials. Figure 4 graphs the post-discrimination percentage of "same" responses for each test stimulus value around each of the four standard angles used as B (36°, 50°, 60°, 76°) and compares these post-discrimination gradients with the single stimulus control gradients around the same standard angles. It is apparent that no significant differences are found in terms of either redistributions of the entire gradient or shift of peak. Table V indicates the percentage of "same" responses which fall to the left of standard angle B when B is 36°, 50°, 60° and 76°. This value is tabled for each per cent occurrence of the standards in the antecedent training series and for the respective single stimulus control gradients. Again, no statistically significant differences are found indicating no reliable shift in post-discrimination gradients associated with low frequency training standards.

TABLE V

Per Cent of "Same" Responses which occur to the Left Side of Standard Stimulus B for each level of Occurrence as Compared with the Same Data for the Single Stimulus Control Gradients

Std Angle B	Single Stimulus Control	Per Cent of Occurrence of Standard B During Training Series 20%	30%	40%	50%
36°	56.07	59.10	62.83	58.34	69.36
50°	59.26	56.40	41.87	42.19	44.83
60°	55.48	65.46	59.31	52.23	50.00
76°	48.98	47.23	43.19	64.64	63.42
	$\overline{X}$	57.04	51.80	54.36	56.90

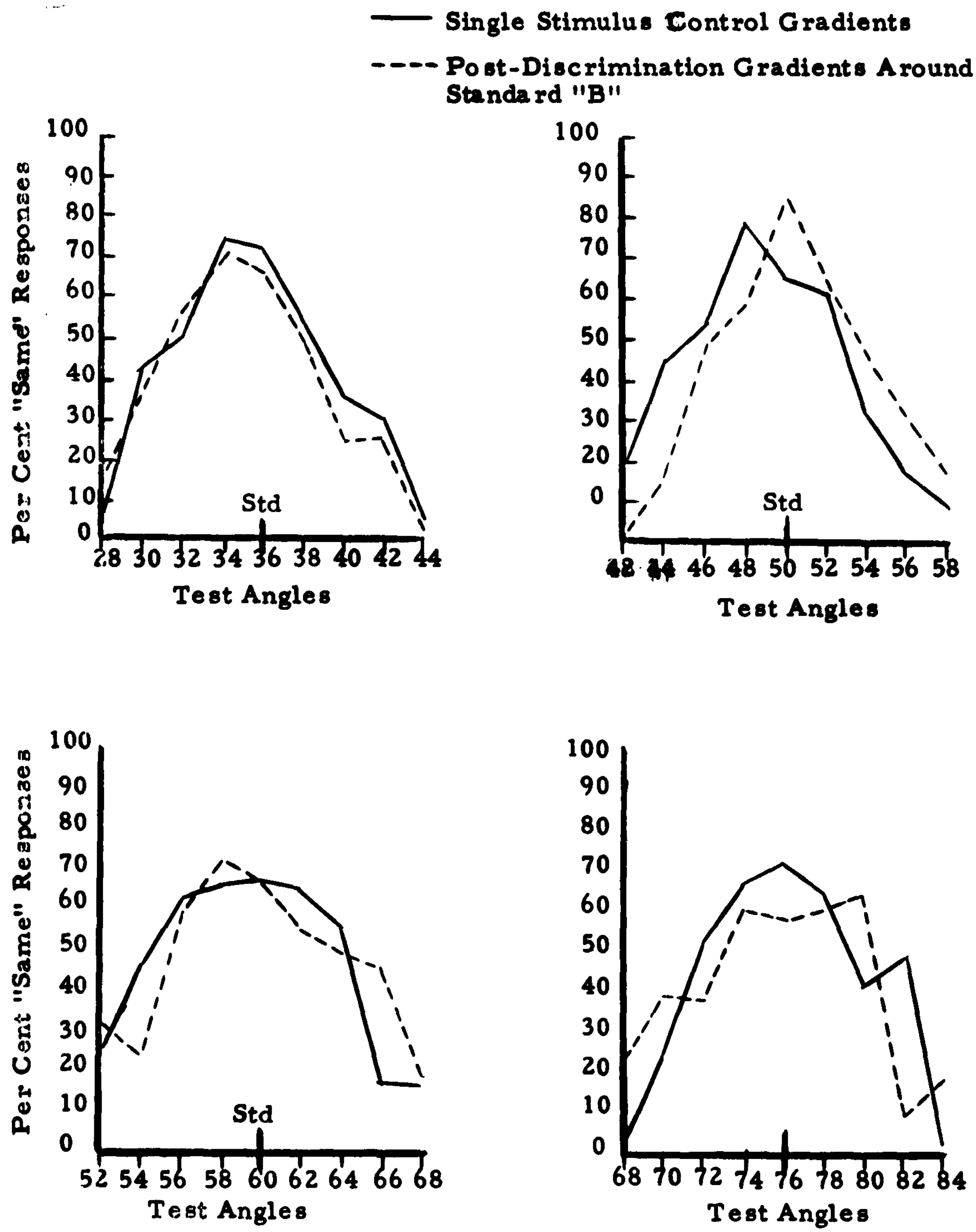

Figure 4. Comparison of Post-Discrimination Gradients Around Less Frequent Standard Angles "B" with Single Stimulus Control Gradients

B. Distribution of "Same" Responses Along the Paired Set Continuum: The Summated Generalization Gradients.

Figure 5 depicts the summated post-discrimination gradients of "same" responses for each discriminated set of standard angles A and B. The data entry is the percentage of the elicited responses which are called "same" for each test stimulus value along the continuum. The data is pooled over levels of occurrence and compared with the appropriate set of single stimulus control gradients. It is apparent that as discriminability between standards decreases from the maximally discriminable set (36° vs. 60°) to the minimally discriminable set (40° vs. 50°) the distribution of "same" responses consistently and significantly changes from clear bimodality toward unimodality. At the two levels of easily discriminated standards (36° vs. 60° and 20° vs. 36°) the maximum number of "same" responses is elicited by test stimuli immediately adjacent to both standards with the intermediate test stimuli eliciting fewer "same" responses than either of the two standards. As discriminability decreases, the maximum number of "same" responses is elicited by test stimuli closer to the midpoint of the test stimulus continuum. At the least discriminable level (40° vs. 50°) the intermediate stimuli elicit 65% "same" responses while standard A elicits 58% and standard B 87%. This increase in the number of "same" responses given to intermediate test stimuli as discriminability decreases represents a significant increase in the total number of "same" responses rather than a redistribution of a constant number since the trend toward unimodality is not accompanied by any significant change in the number of "same" responses given to either standard.

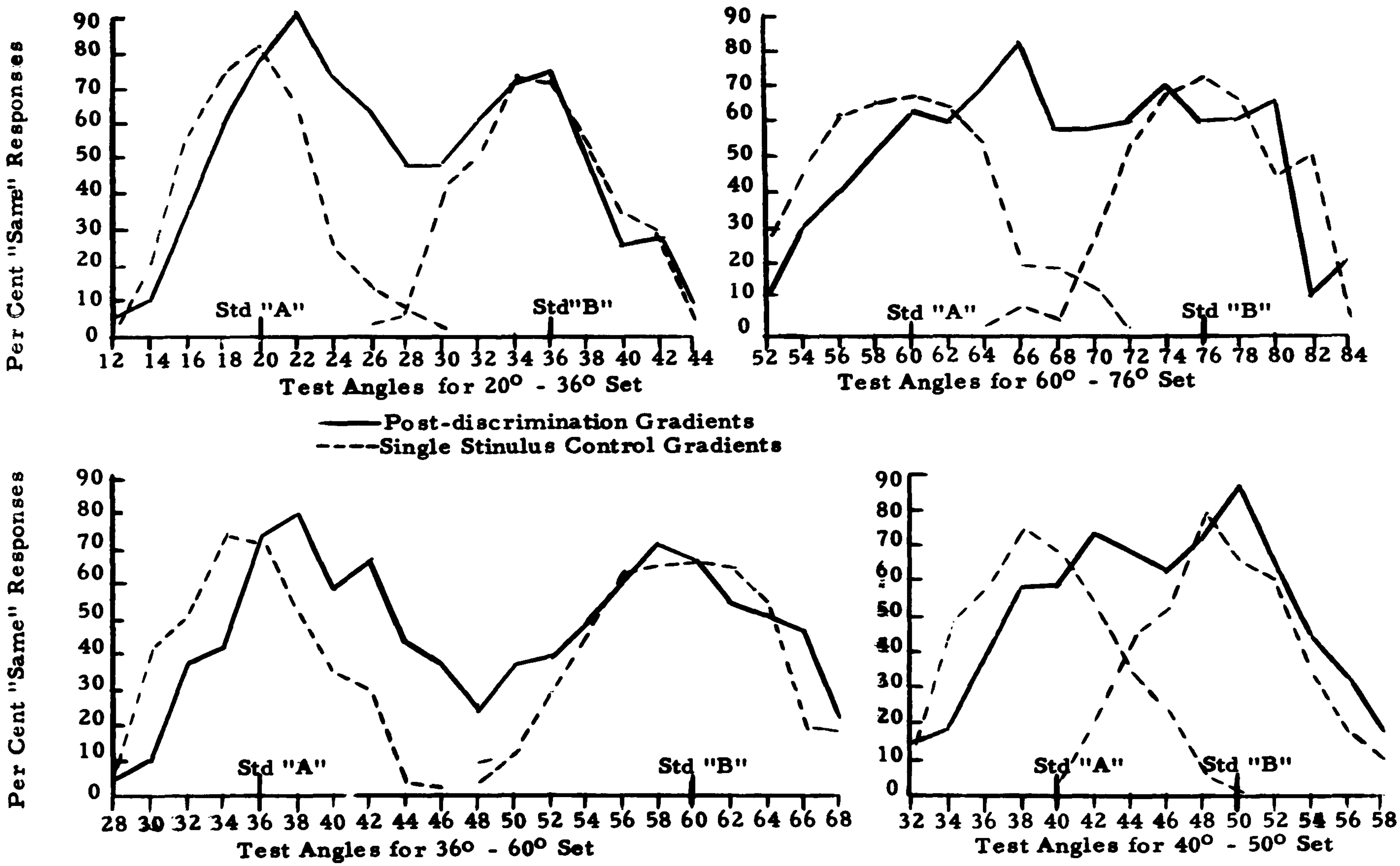

Figure 5. Post-Discrimination Gradients of "Same" Responses for Sets of Discriminated Standard Angles "A" and "B" Compared with Single Stimulus Control Gradients

A statistically significant effect of frequency of occurrence is noted on the number of responses given to the mid-point stimulus of the test continuum after differing frequencies of occurrence in training. Reflecting the significant shift of the post-discrimination gradients as a function of per cent occurrence of standard A in the training series, an increasing number of "same" responses is elicited by the mid-point stimulus of each test continuum as the per cent occurrence of the standard A increases. Indication of this is given in Figure 5 by the discrepancy between the extreme left side of each summated generalization gradient and the corresponding side of the single stimulus control gradient. No such discrepancy in comparable distributions is noted at the extreme right or standard B side of the gradients, reflecting no significant differences in shift as a function of the lower per cent occurrence levels.

CONCLUSIONS

With reference to the underlying concepts of the Estes-Burke model, correct association of the prediction of one event (from a set of alternatives) with the actual occurrence of the predicted event adds some increment to the probability that the same predictive response will be elicited on the subsequent trial. The actual increase in probability is a constant fraction of the amount remaining to be learned which in turn is the difference between perfect response evocation and the immediately present probability of specific response occurrence. Although the model is strictly one of contiguous association with no reinforcement concepts, the generated learning curves are identical in form to those derived from reinforcement type theories. In this sense, then, the "prediction with immediate feedback" trials of the training series of this study may be considered to be functionally equivalent to the "variable interval reinforcement training" trials of the Guttman and Hansen studies.

On this basis, the results of this study do not clearly substantiate the general applicability to discrete response behavior of Guttman's conclusion that low rates of reinforcement are as inhibitory as no reinforcement when the low rate is combined in a discrimination task with a high rate for the alternative stimulus. Although the more frequently reinforced standard A did, in general, tend to elicit the greater number of "same" responses at each discriminability level, there was no consistent relationship between the actual number of "same" responses and the differential frequency of occurrence of the standard in the training series. The consistent relationship found as a function of differential reinforcement was one of redistribution of approximately the same numberof "same" responses around the more frequent standard A at all levels of discriminability. As frequency of the standard increased to its maximum occurrence level of 80% of all training trials, the subsequent post-discrimination gradient shifted farther toward the intermediate test stimulus values, a finding more consistent with Hanson's study although with reversed direction of shift. The effect of differential reinforcement on the low frequency standards B does not offer some evidence in support of Guttman's statement if one consider inhibition in the discrete trial discrimination task to be an insensitivity to differing levels of the experimental variable. No significant differences in the distribution of "same" response in the post-discrimination gradients around standard B were noted on any of the low frequencies or at any of the discriminability levels. Regardless of the frequency of the standard during training and the similarity of alternative stimulus, the post-discrimination gradients around standard B were essentially the same.

In terms of peak shift, the directional difference in comparison with Hanson's and Guttman's work has already been noted. With higher rates of reinforcement, the post-discrimination gradient shifted its peak toward the intermediate test stimuli rather than toward the extreme, not a surprising finding since the effect of low rates of reinforcement in this study were not behaviorally inhibitory.

In summary, neither of the general predictions derived from the operant discrimination tasks are clearly applicable to the discrete trial discrimination task. Low rates of reinforcement were not inhibitory in the sense of response extinction, only in the sense of insensitivity. Post-discrimination gradients associated with high reinforcement schedules were redistributed along the test continuum at distances related to frequency of occurrence or reinforcement in the training series. Since responses associated with low frequency standards were not inhibited, the summated generalization gradients result from an interaction between two positive gradients, one distributed around each standard, with peak values and modality related more to discriminability than to differential reinforcement. With easily discriminated standards the gradient is bimodal, indicating little interaction between the two separate gradients. The peak around standard A shifts toward intermediate test stimuli while that around standard B is essentially invariant. As discriminability between the alternatives decreases, the summated generalization gradient tends toward unimodality with peak at the intermediate test stimuli and no loss in frequency of response to the two standards, a finding in agreement with the operant equal reinforcement discrimination studies of Guttman and Kalish.

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